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ENSR®

Arizona Hazardous Air Pollution Research Program Executive Summary

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December 1995

Document Number 0493-013-920

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EXECUTIVE SUMMARY

In response to Arizona Revised Statutes section 49-426.08, the Arizona Department of Environmental Quality (ADEQ) and the Arizona Department of Health Services (ADHS) have undertaken a hazardous air pollution research program. The purpose of the program is defined by the statute: "... to evaluate the existing risk to public health related to hazardous air pollution and to provide options and recommendations for programs to control the release of hazardous substances into the ambient air." This report describes the research program and presents its findings.

Introduction to HAPs and Risk Assessment

Hazardous air pollutants (HAPs) are substances (gases or particles) in the air that may threaten human health through inhalation or other exposure routes. Excluded from this definition are those air pollutants for which National Ambient Air Quality Standards have been established -- sulfur dioxide, nitrogen dioxide, ozone, carbon monoxide, particulate matter (PM_{10}), and lead -- except that lead was considered in this research program.

HAPs are released into the air from a wide variety of sources. The principal sources are combustion of fuels in engines and for heating, and uses of solvents and other chemicals. The emissions arise from motor vehicles, industries, businesses, and common household activities. An example of a less obvious source of HAPs is from evaporation of chlorinated swimming pool and domestic water. Also, dust from soils and rocks can contain naturally occurring, small amounts of some HAPs.

Exposures of people to HAPs depend on where they live, what HAPs are present in the air in that area, and how long they live there. HAPs can enter the body directly through breathing, which was the pathway of greatest importance in the research program. Additionally, HAPs in particles settle out of the air and onto the soil (but that pathway was found to be insignificant in Phoenix).

Effects from HAPs on human health can be acute, meaning that a brief exposure of minutes or hours can cause an effect, such as respiratory dysfunction. They can also be chronic, in which case effects occur after many years or a lifetime of exposure, an example being contracting cancer. Acute effects require higher concentrations of HAPs than do chronic effects.

The hazard to human health from exposure to HAPs is estimated by a process called "risk assessment." In risk assessment, information from laboratory tests with humans and animals and from human health studies is used to estimate what effects might be caused to people by specific concentrations of HAPs. The hazardous air pollution research program carried out risk assessments to estimate health risks from HAPs in Arizona.

Implementation of the Research Program

ADEQ began planning the research program in [redacted], when it contracted with ENSR Consulting and Engineering to prepare a general research plan and to develop a list of hazardous air pollutants for consideration by the research program. The plan underwent national peer review before finalization in May 1994. The list of pollutants to be considered, the ~~Arizona Research HAPs List~~, was ~~finalized in April 1994.~~

ADEQ started the first operational activities of the research program in April 1994, when it initiated ambient HAP measurements in Phoenix. The measurement program has since been expanded to include additional sites within the state.

In late December 1994, ADEQ awarded a contract to coordinate and conduct major operational portions of the research program. A team of atmospheric research organizations, led by ENSR Consulting and Engineering as prime contractor, was selected for this work. This team carried out most of the technical activities of the research program. ADEQ retained responsibility for conducting the ambient HAP measurements, in coordination with the contractor team, who also conducted laboratory analyses of the atmospheric samples.

Research Program Approach

The activities done during the HAPs research program are portrayed graphically in Figure ES-1. This approach was developed in the research plan and was reviewed and refined in February 1995 in a two-day workshop with representatives of ADEQ, ADHS, Maricopa County, and the University of Arizona, which resulted in the research program operational plan. A second workshop in August 1995 reviewed progress and provided further refinements to the analysis approach. A third workshop in November 1995 reviewed the findings of the study that are presented in this report.

The research efforts began with the preparation of the HAPs research plan. Techniques for measuring HAPs in ambient air, estimating source emissions, performing atmospheric modeling and conducting risk assessments were evaluated in the plan. Those evaluations provided a basis for the approach that was followed during the research program.

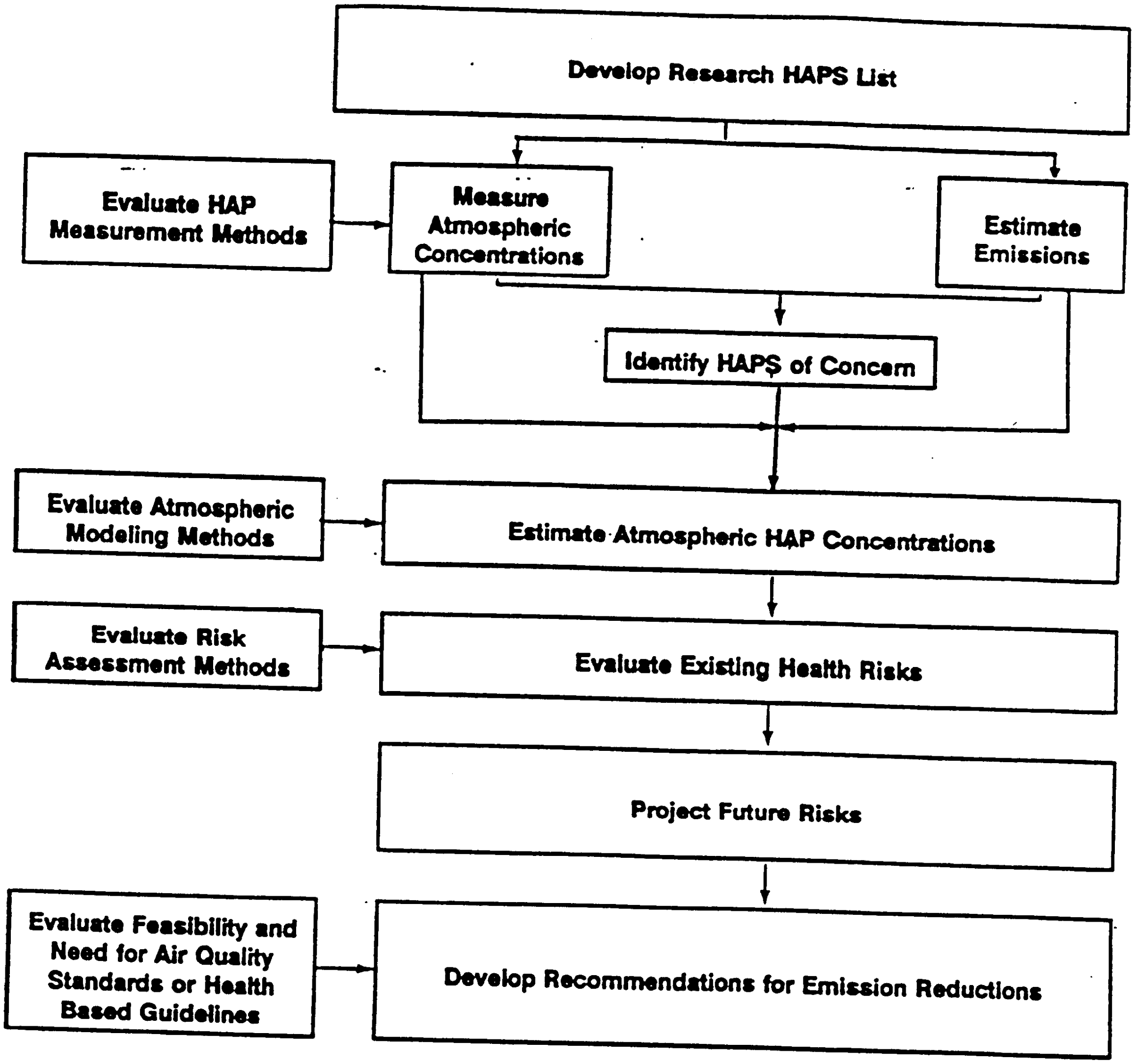

Figure ES-1. Hazardous Air Pollution Research Program Tasks

In conjunction with the preparation of the research plan, a Research HAPs List of 676 substances and substance classes was developed from a list of over 1000 substances that may be associated with human activities. Substances were selected for the Research HAPs List based on their potential for posing an adverse effect on human health.

Because the research program was the first comprehensive study of HAPs in Arizona, it was necessary to focus its resources in order to obtain meaningful results within a reasonable time frame and budget. Therefore, the program analyzed conditions in four geographic regions -- the areas of Phoenix, Tucson, Casa Grande, and Payson -- that represent a large fraction of the state's population and are characteristic of many of the types of communities in the state.

During the research program, measurements of atmospheric HAP concentrations were made in all four regions. Because the health risks were to be estimated for the general population, these measurements were made primarily in residential neighborhoods. No attempt was made to measure ambient HAPs in the vicinity of major sources. Therefore, this report does not address risk at "hot spot" locations. Additional measurements were made at a remote rural location to characterize HAP concentrations that are not directly attributable to emissions in the regions (i.e., "background" values).

In addition to the regular ambient measurements, information on the types of HAPs emitted by some sources was obtained by making measurements in the vicinity of those sources. These measurements were made to characterize emissions from these sources and were not used for the risk assessments. Also, special studies were conducted in Phoenix to quantify the proportions of various species in the emissions from gasoline- and diesel-powered motor vehicles.

A detailed inventory of emissions from all known sources of HAPs in the four regions was developed in order to determine which HAPs might be present in the four study regions and to provide input for the atmospheric simulation modeling that was done to estimate the spatial distribution of HAPs concentrations in each region. Emissions estimates for motor vehicles were developed from traffic data. Information from county and ADEQ permit files was a basis for estimating emissions from over 300 individual facilities and over 100 types of small, dispersed sources. (Examples of such dispersed sources include small facilities, such as chrome platers, neighborhood dry cleaning facilities, and gas stations; and activities such as painting, and burning wood for home heating. Individually, these sources are small, but collectively their emissions can be important sources of HAPs.)

Those HAPs most likely to be in the ambient air in Arizona were determined from the ambient measurements and estimates of emissions. The chemicals of greatest potential concern, called chemicals of interest (COI), were then selected for further analysis. About 25 COI, out of the 169 HAPS with emissions and toxicity data, were selected for each region. The selection was made on the basis of rankings of relative risk based on estimates of emissions and toxicity, supported by measurements of ambient concentrations.

For these COI, human health risks in each region were estimated by a well-established quantitative health risk assessment approach, as developed by the National Research Council. The process involved (1) identifying the chemical species of interest (the COI); (2) assessing their toxicity based on dose-response information published by the U.S. EPA and California EPA; (3) determining the exposure of the population to these COI from ambient measurements and atmospheric simulation model predictions of HAPs concentrations; and (4) characterizing health risks due to these exposures, considering acute and chronic exposures, carcinogenic and non-carcinogenic effects, and various age groups in the population.

The atmospheric simulation model that was used to calculate the distributions of ambient concentrations of HAPs over space and time simulated the transport and dispersal of emissions by wind and atmospheric turbulence and the settling of particles to the ground. The simulations were made for modeling domains encompassing three of the study regions, as indicated in Figure ES-2. Because of its small scale and topographic and meteorological complexity, concentrations in Payson were not determined by modeling, but rather were determined from the HAP and PM_{10} measurements made there, through a statistical technique called "receptor modeling." Receptor modeling uses the chemical "signatures" of pollutant emissions from various types of sources to estimate the relative contributions of those sources to measured ambient concentrations.

Alternative approaches for controlling or reducing HAPs emissions in the future were considered during the research program.

A public information leaflet about the HAPs research program was prepared and distributed. Recommendations have been made to ADEQ for educating the public about the research program's findings, and additional materials will be prepared to disseminate and interpret the research results.

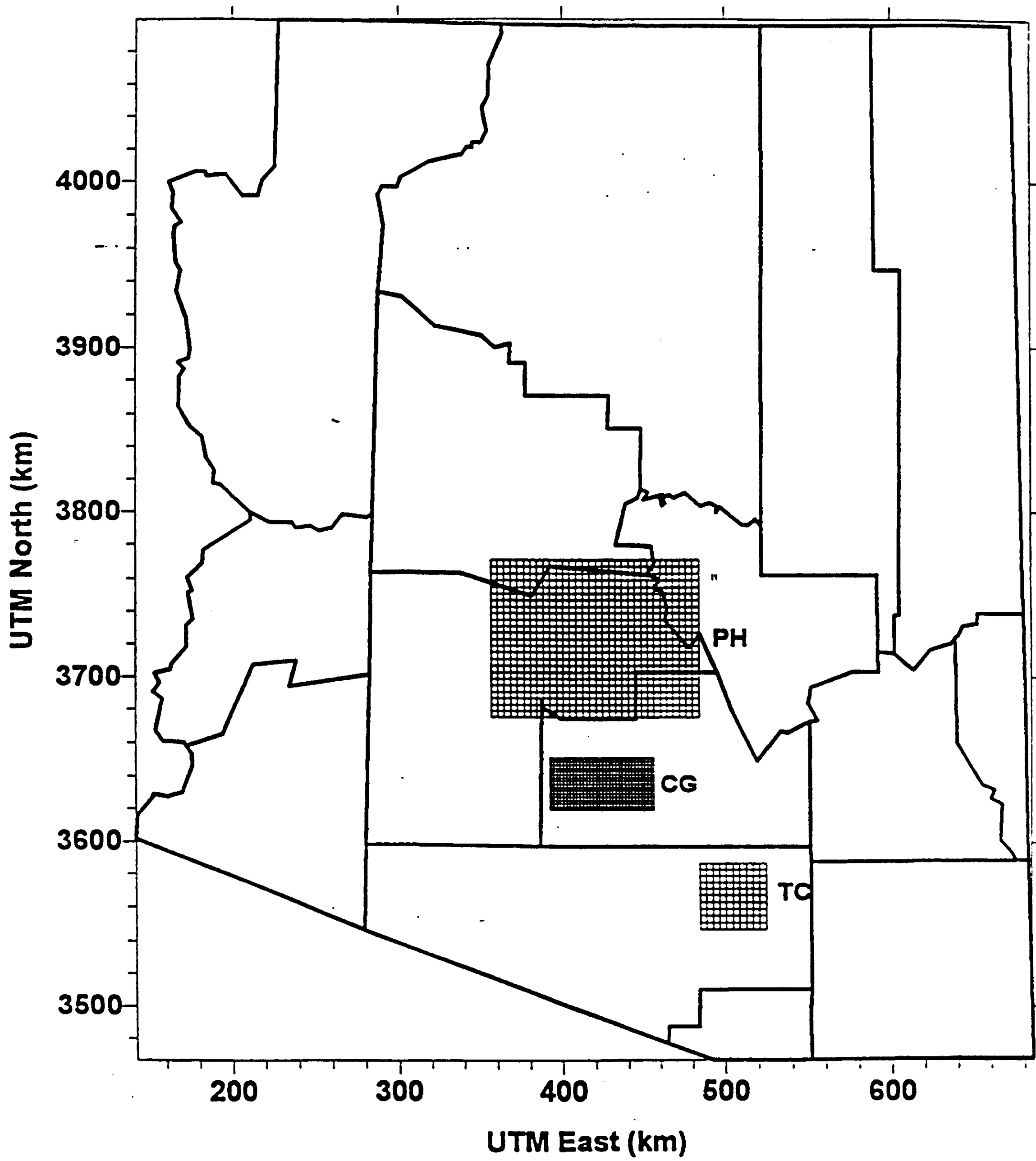

Figure ES-2 Modeling Domains and Grids

Risk Assessment Approach

Exposures based on HAPs concentrations (measured and modeled) were used to evaluate risks to health. Two general types of "receptors" were selected as representative examples of the general population. A ~~"reasonable maximal exposure (RME) receptor" was designed~~ to ~~represent people who may have high exposures to HAPs~~. A "~~central tendency case~~ (CTC) receptor" was designed to represent people who may have what are considered to be average exposures to HAPs. The results of these two cases provide a realistic range of general exposures to HAPs and, consequently, a range of human health risks associated with those general exposures. Using the predicted distributions of various concentrations in each study region, the RME receptor was assumed to be exposed to the 95th percentile concentration of each COI and the CTC receptor was assumed to be exposed to the median concentration. The research only addressed typical residential neighborhood exposures, and did not attempt to identify any "hot spots" or to quantify exposures in them.

Current risk assessment guidance recommends the use of upper-bound values in the risk calculation, which ensures that the resulting risk estimate will be likely to overstate actual risk to any one individual. In order to make informed decisions based on risk assessment results, however, it is necessary to understand not only this upper bound risk but also the range of potential risks and the assumptions associated with that range. In this research program, the range of exposures was determined by using probability distributions of the concentrations, exposure frequency and duration, averaging period, inhalation rate, and body weight in the exposure calculations, using a Monte-Carlo sampling process to calculate the resulting distribution of exposures. This approach is known as a "probabilistic" risk analysis.

Given estimates of exposures, the potential for adverse health effects to occur as a result of those exposures was estimated. The evaluation of most noncancer effects, acute and chronic, was based on a threshold for toxic action of a substance. For most carcinogenic compounds, on the other hand, no threshold was assumed, so that any level of exposure, no matter how small, carried with it a finite probability of evoking an adverse effect. That probability, determined from values provided by the EPA, represents an upper bound estimate of the risk of contracting cancer as a result of the evaluated exposure. "Upper bound" means that the true risk, which cannot be precisely defined, is not likely to be higher, but may be lower (and may be close to zero in some cases).

The carcinogenic risk characterization estimated the upper bound likelihood, over and above the background cancer rate, that a receptor would develop cancer in one year of his or her lifetime as a result of exposures to the HAPs evaluated as COI. This risk was used to estimate the annual excess cancer risk, which represents the probability of cancer occurrence from the given level of exposure, in excess of the probability of cancer in the absence of the exposure.

The potential for adverse noncarcinogenic health effects was estimated for each receptor and COI by comparing the average daily dose for chronic exposure to each compound with the "Reference Dose" for that compound. The resulting ratio, known as the Hazard Quotient (HQ) for that compound, is a measure of the possibility of risk. An HQ below one represents no risk, while an HQ larger than one indicates the possible presence of risk. For risks due to more than one chemical, the HQs were added together to calculate a hazard index (HI).

Risk evaluations were made for each region for two time periods. Health risks were first evaluated under concentrations based on current estimates of emissions and the current ambient monitoring data. Health risks were also estimated under conditions that may exist in 2005, after full implementation of emission controls mandated by the 1990 Clean Air Act Amendments and including the effects of other expected emissions changes as well as growth in population.

In order to determine the categories of sources that were the primary contributors to the risks, two complementary techniques were used to attribute concentrations, and hence risks, to source categories. The primary approach was that of attributing the relative contributions of emissions from various sources to the atmospheric concentrations of individual HAPs, according to the fraction of region-wide emissions accounted for by each type of source. The other approach, receptor modeling, used measured atmospheric concentrations of several chemical species, including HAPs, to estimate source contributions from a limited number of source categories. For the receptor modeling approach, the relative amounts of certain key species in atmospheric samples served as a "fingerprint" to identify and quantify the presence of the emissions from a specific source category in the atmosphere.

Current Health Risk Estimates

To illustrate the distribution of risks indicated by the risk analysis, Figure ES-3 shows the distribution of annual excess cancer risk for a lifetime resident that is exposed to current HAPs levels in Phoenix. The RME (upper bound) point estimate of risk is about 8 cases per year per million population, a value that is substantially higher than most of the distribution and has an extremely low probability of occurrence. The CTC (central tendency case) estimate of 1.4 cases per year per million people, which is slightly below the median estimate of 2.3 per million, corresponds to the most probable estimate. Figures ES-4 through ES-6 show similar distributions of excess cancer risks for Tucson, Casa Grande, and Payson. In all cases the CTC estimate of risk is below the median value. In Tucson and Casa Grande,

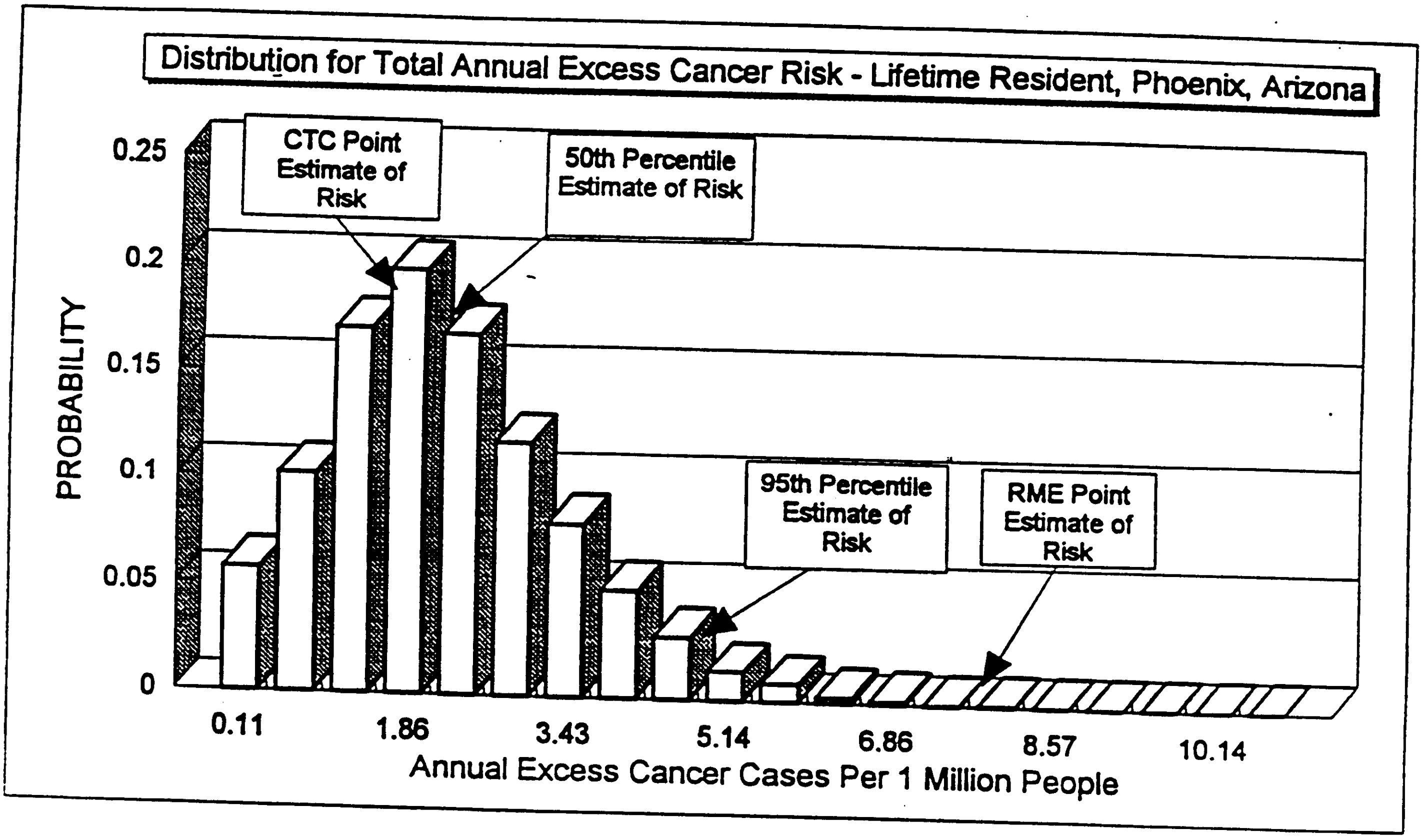

Figure ES-3. Distribution of Annual Excess Cancer Risk for Lifetime Resident of Phoenix

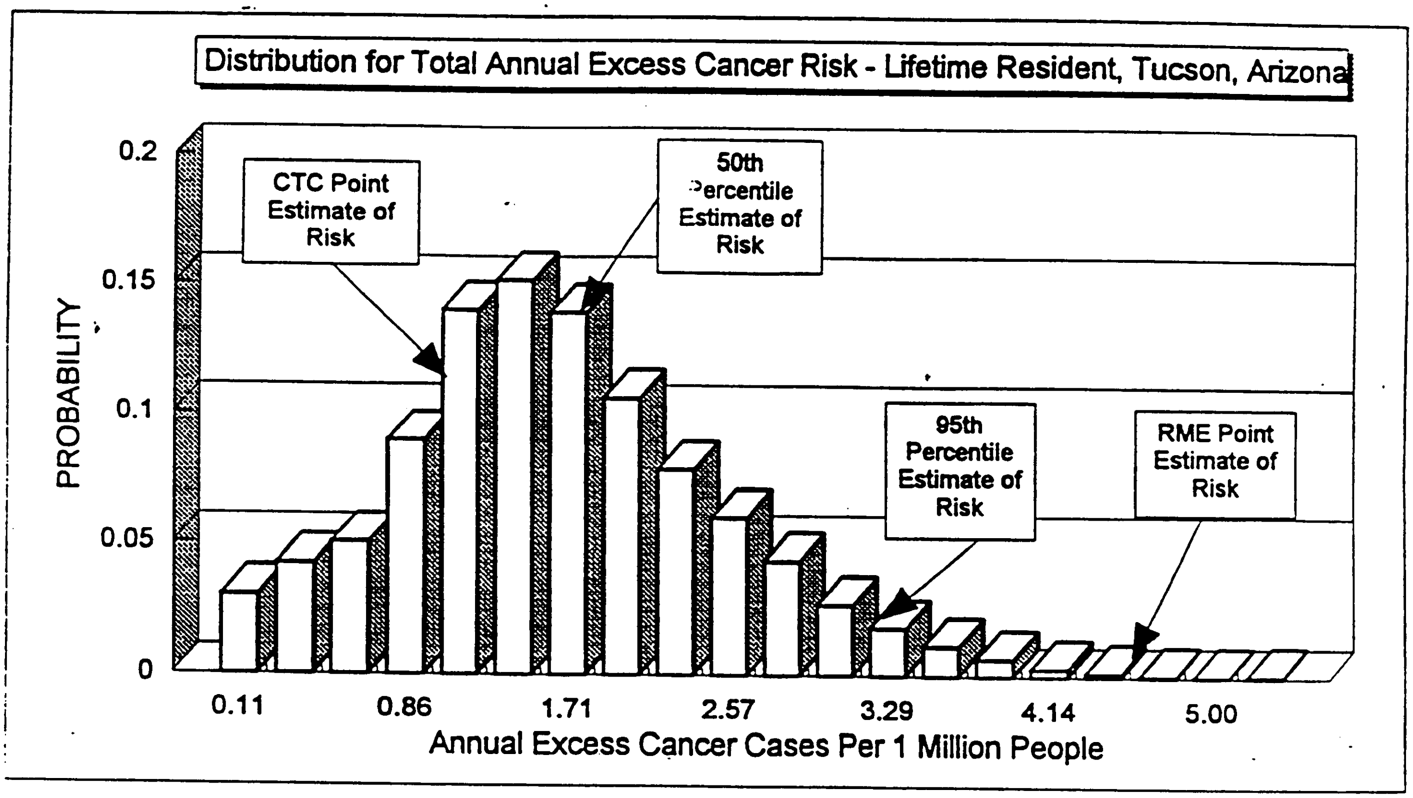

Figure ES-4. Distribution of Annual Excess Cancer Risk for Lifetime Resident of Tucson

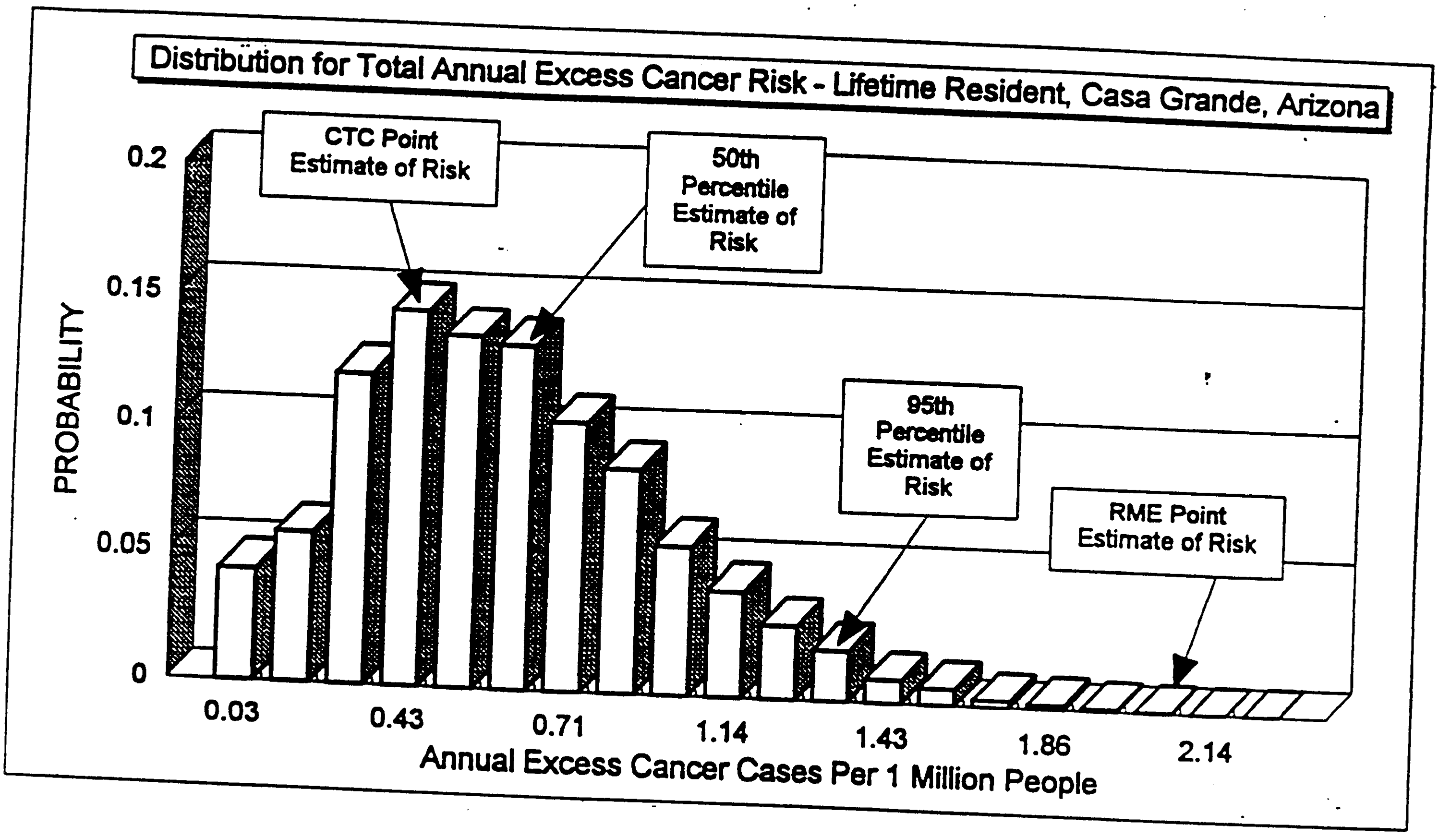

Figure ES-5. Distribution of Annual Excess Cancer Risk for Lifetime Resident of Casa Grande

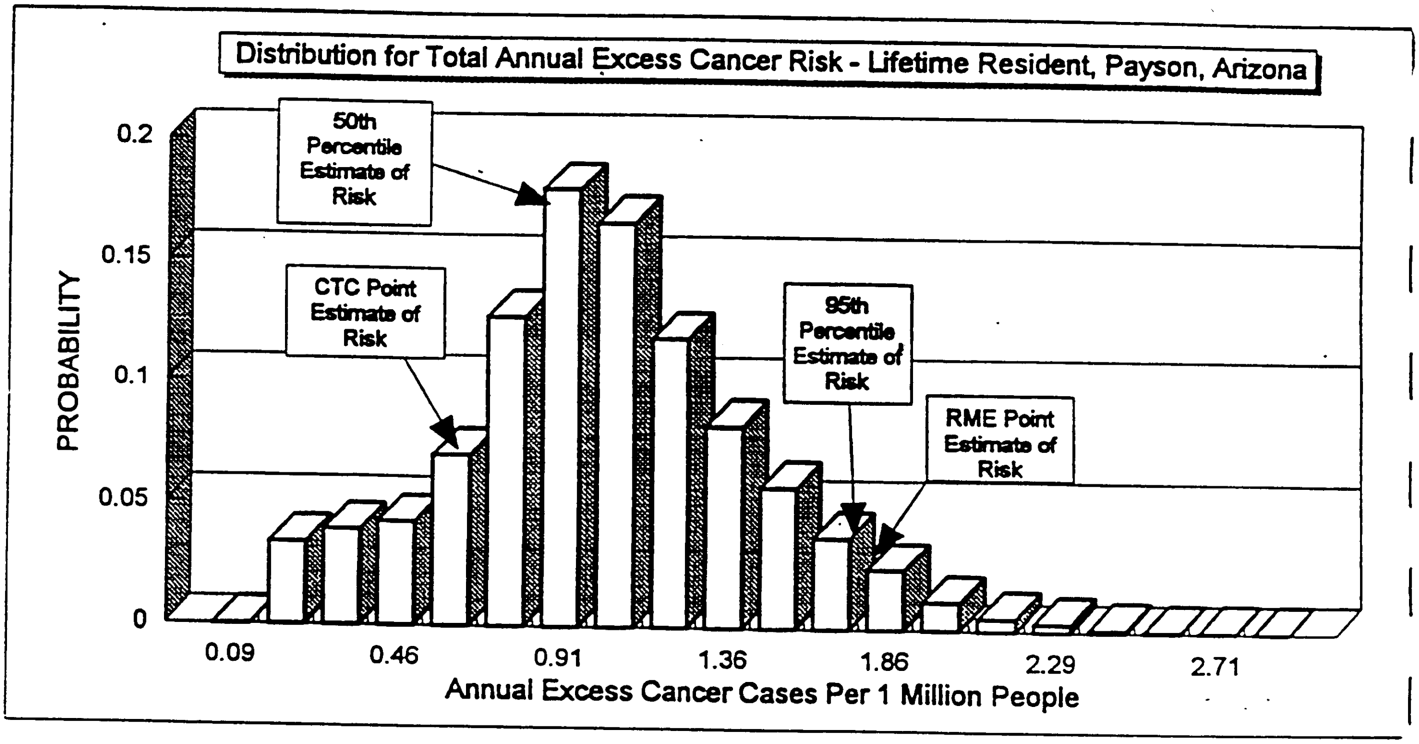

Figure ES-6. Distribution of Annual Excess Cancer Risk for Lifetime Resident of Payson as in Phoenix, the RME risk is much greater than the 95th percentile because the distributions have long "tails". In Payson, however, the RME estimate is quite close to the 95th percentile because the distribution there is less spread out than in the other regions.

Comparing the risks in the four regions, the estimated current annual excess cancer risk is largest in Phoenix, as shown in Figure ES-7. The estimate for the reasonable maximal exposure (RME) case for Tucson, 4.5 cases per year per million people, is about 60 percent of the value for Phoenix, while the RME values for Casa Grande and Payson (2.0 and 1.8, respectively) are about 25 percent of the value for Phoenix. The higher probability CTC values were much lower than the RME values, in the range of 1.2 to 1.4 excess cases per year per million population in the two major urban areas and from 0.4 to 0.6 in the smaller communities of Casa Grande and Payson.

The estimated current RME [redacted] with a CTC hazard index (HI) of 6 and an [redacted] Values in the other three regions are substantially smaller, with CTC indices of 3 to 5 and [redacted] In contrast with the regional differences estimated for excess cancer risk, the values of the total HI in Tucson, Casa Grande and Payson are all about the same. The total HI exceeded one and was highest for potential respiratory effects in all four of the regions. It also exceeded one for both neurological and blood effects in Phoenix and Casa Grande and for blood effects in Tucson.

It is useful to note that the risks presented here represent risks to the general population and may not apply to individuals who live or work near major sources of HAPs and who may, therefore, be exposed to higher concentrations than the general population. The scope of the research program did not address localized "hot spots" due to specific sources.

Causes of Risks

The [redacted] that contribute substantial fractions of the estimated RME annual excess cancer risk [redacted], for the most part, [redacted]ns, as shown in Figure ES-9. The organic species [redacted], a product of combustion of fossil fuels (such as in motor vehicles and lawn and garden equipment engines) and of wood burning, [redacted]. [redacted] (a component of gasoline and a product of wood combustion) and [redacted] (from internal combustion engines and atmospheric reactions) also contribute significantly in all of the regions. [redacted] to its formation.

7
4
1.8
1.5
10.6/10[6]
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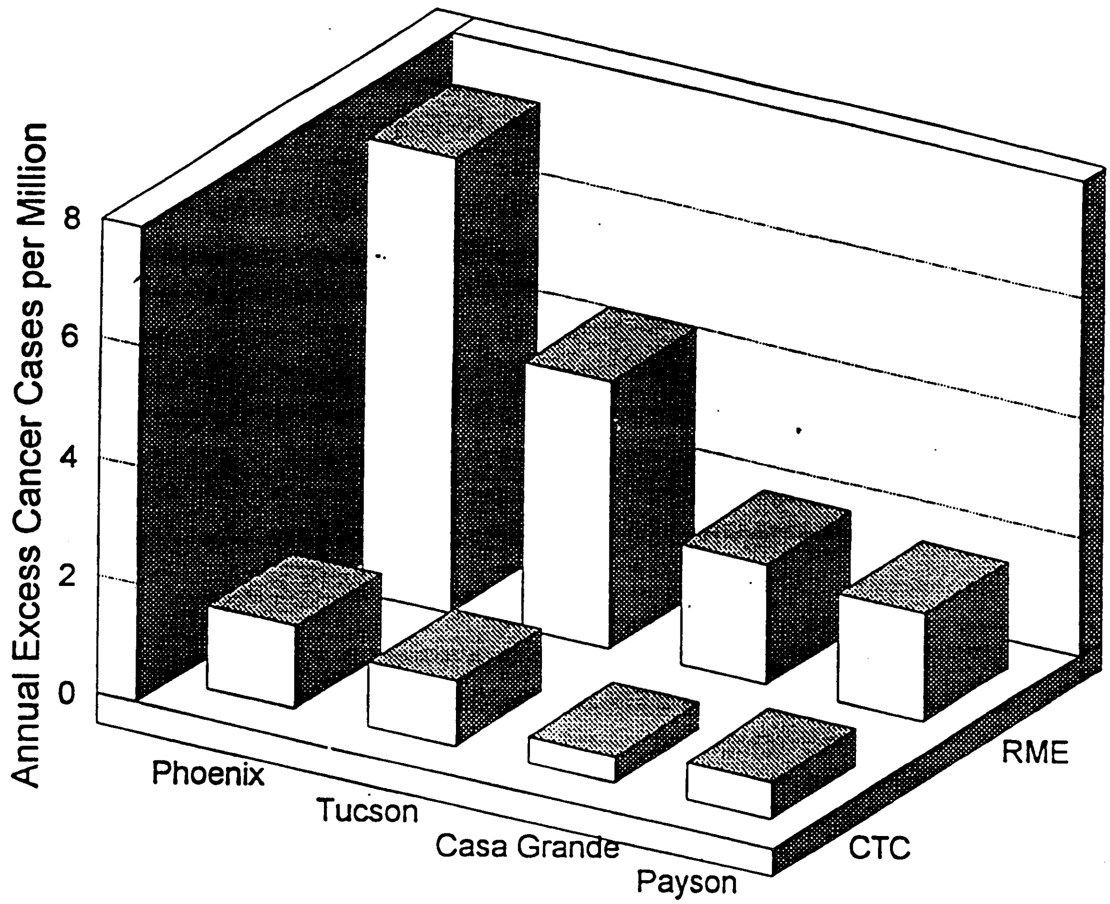

Figure ES-7 Comparison of Estimates of Current Annual Excess Cancer Risks

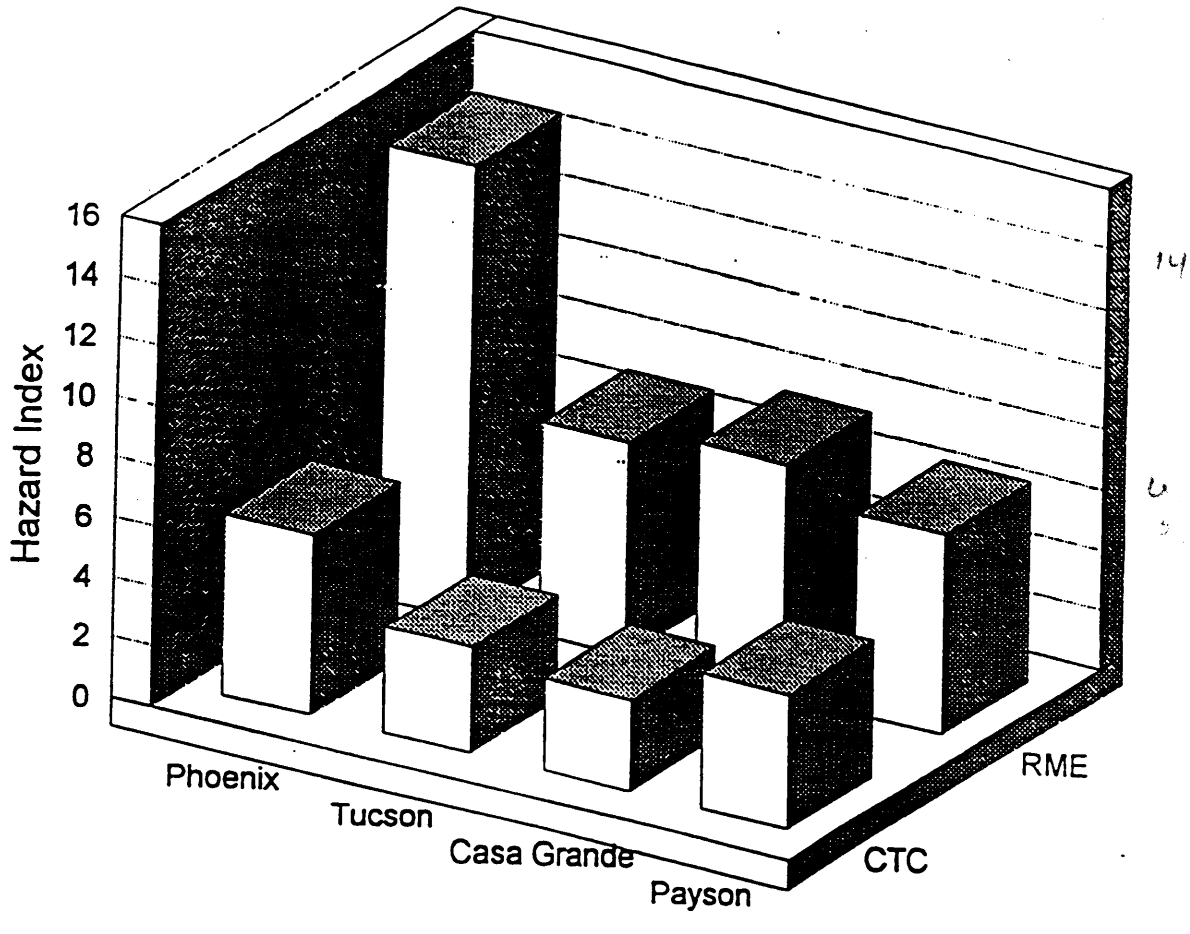

Figure ES-8 Comparison of Current Total Non-Cancer Hazard Indices

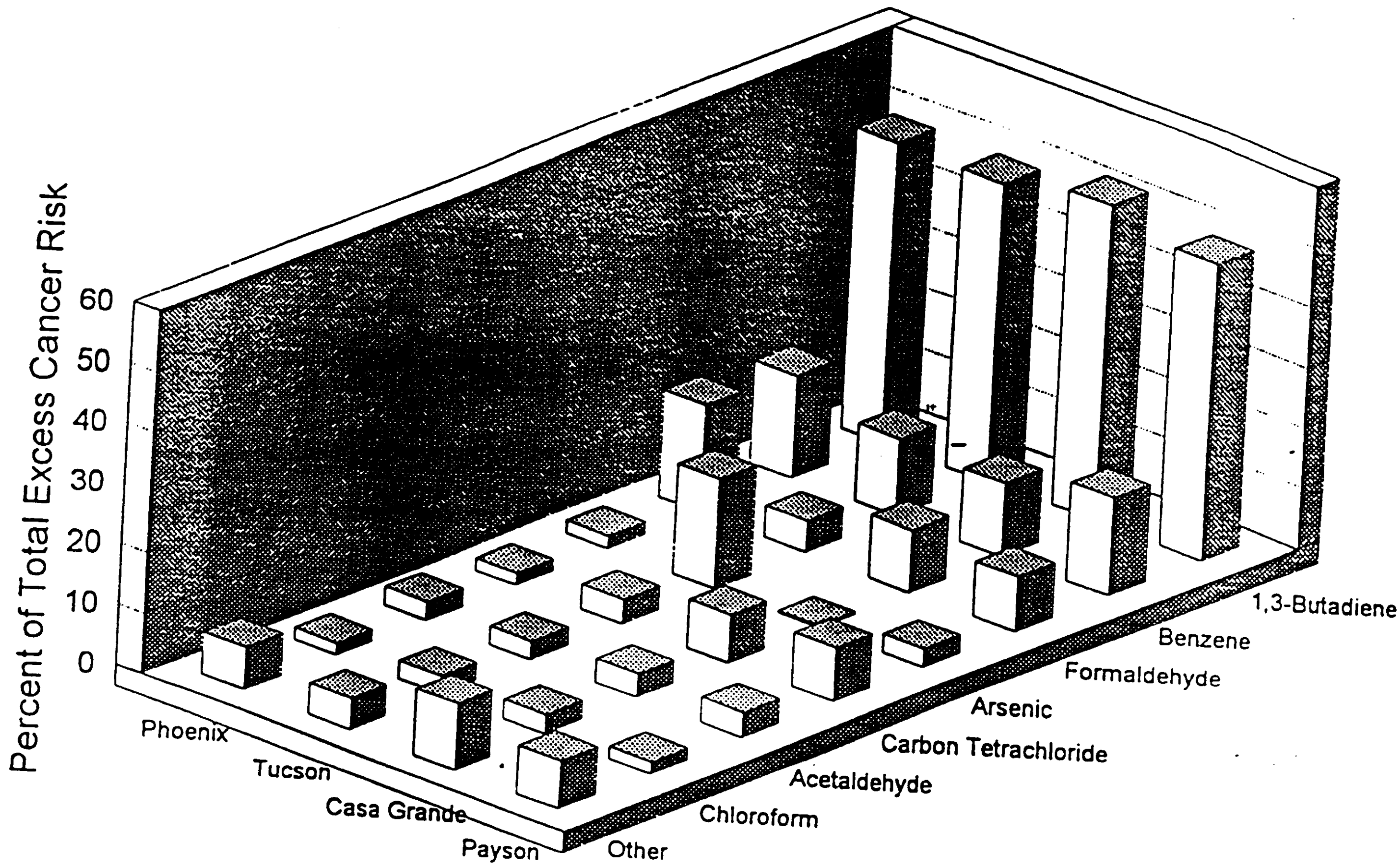

Figure ES-9 Contributions of HAPs to Estimated Current RME Annual Excess Cancer Risk [redacted] is a major contributor in Tucson, but not in the other regions. Receptor modeling indicated that it came from outside the region. Smelter emissions from various locations outside the Tucson region are a likely source.

Lead was not a significant risk factor in any of the regions. Also, risk from HAPs via other pathways than inhalation was evaluated for the Phoenix area and was not found to be meaningful in comparison to the inhalation risks. Acrolein, emitted primarily by motor vehicles, was the major contributor to potential non-cancer respiratory effects in all four regions, with smaller contributions from acetaldehyde (another motor vehicle engine combustion product) and manganese (from soil dust suspended by vehicles and construction). Benzene was the major contributor to potential blood effects, in the regions where such effects might occur, and manganese was the major contributor to potential neurological effects.

Although Casa Grande was selected as a study region to evaluate potential risks from agricultural chemicals, these chemicals did not contribute significantly to either cancer or non-cancer risks. Their negligible influence appears to be a result of their use in areas removed from population centers in the study region.

As seen in Figure ES-10, motor vehicles were estimated to be the largest or second-largest contributor to the RME annual excess cancer risk in all of the regions, with substantial contributions from small internal combustion engines in lawn and garden equipment in Phoenix, Tucson and Casa Grande. Wood burning was estimated to be the greatest contributor to the current cancer risk in Payson, largely because of emissions of 1,3-butadiene and benzene.

Future Health Risk Estimates

Future changes in HAPs emissions might occur because of factors such as product substitution, a new Maricopa County SIP, or vehicle fleet turnover, as well as because of general population and vehicle usage growth. Also, the 1990 Clean Air Act Amendments (CAAA) mandate reduction of HAP emissions from various industries over the next several years. Consequently, the U.S. EPA is establishing, and phasing in over the next seven years, Maximum Achievable Control Technology (MACT) standards for over 179 classes or categories of sources. Also mandated by the 1990 CAAA, other sources may be subject to regulation under the Area Source Program.

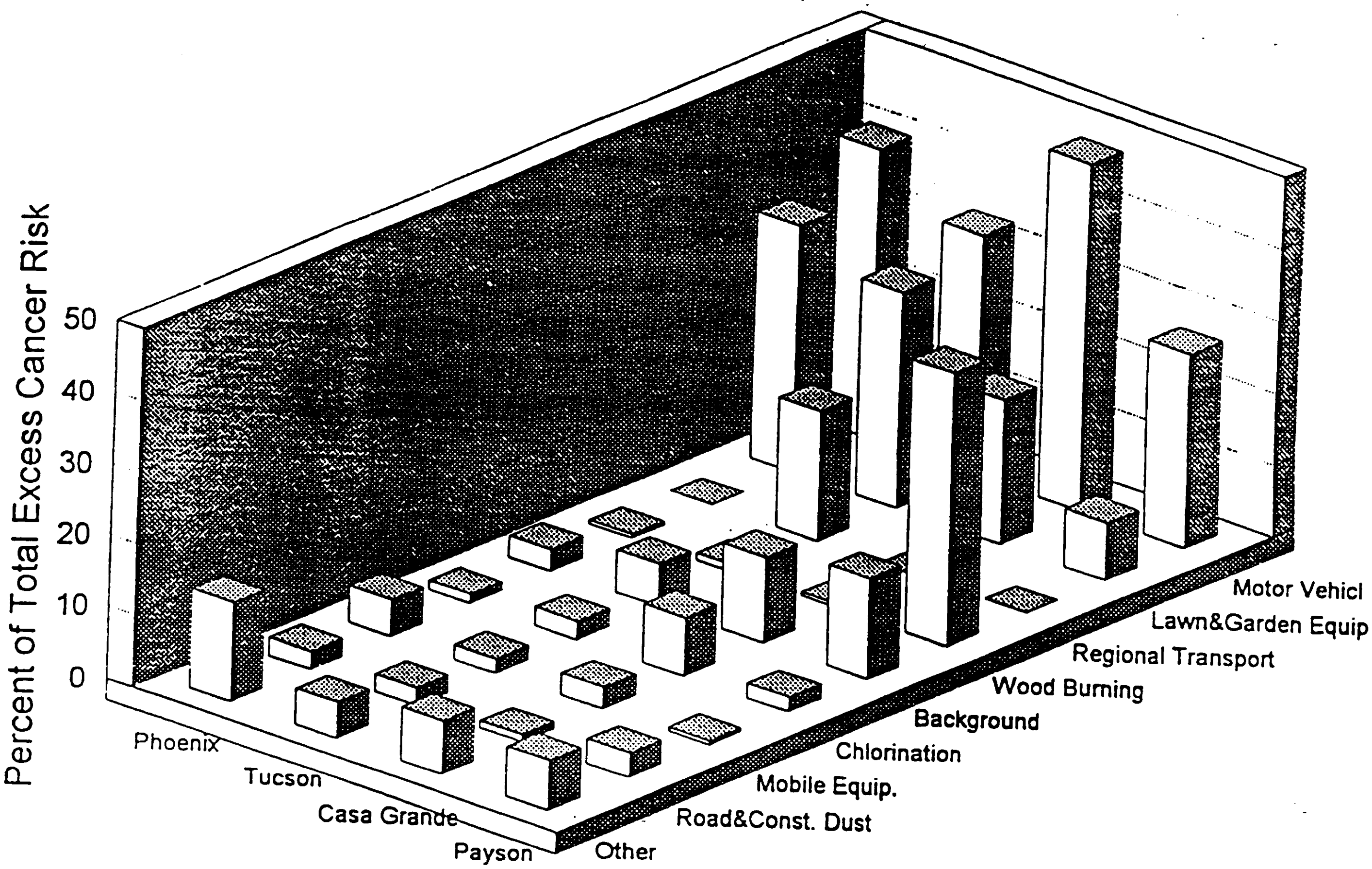

Figure ES-10 Contributions of Sources to Estimated Current RME Annual Excess Cancer Risk

Annual excess cancer risk is expected to decrease in the future in all three regions, as shown in Figure ES-11, with the largest decrease occurring in the Phoenix region. The RME total HI is expected to decrease somewhat in the Phoenix region but to remain about the same in the other three regions, as seen in Figure ES-12. The future distribution of the annual excess cancer risk among source categories is expected to be similar to the current distribution, with the exception of a substantial reduction in the contribution from wood burning in Payson.

Implications for Other Parts of Arizona

The similarities among the four study regions in the HAPs and emission source types that are major contributors to risks suggest that ~~1,3-butadiene and benzene~~ emitted by motor vehicles and small internal combustion engines ~~are probably also the major contributors to risk in the rest of the State, with some exceptions~~. It is possible that ~~arsenic~~ emitted from primary metal smelting operations could contribute significantly to cancer risks in areas ~~in the vicinity of these operations~~. (This is the subject of an ongoing ADHS study and therefore was not addressed here.) Wood burning in higher elevation communities, such as Flagstaff and Show Low, could contribute significantly through 1,3-butadiene and benzene emissions.

The levels of risk depend on both emissions and on atmospheric dispersal of HAPs after they enter the atmosphere. Therefore, it is difficult to estimate risk levels in other parts of the State without estimates of both emissions and atmospheric dispersal characteristics. However, risks are expected to be lower in the rest of the state than they are in the Phoenix region, because of the relatively large emissions associated with the large population in that region. The risks that were estimated for Payson may be similar to risks in other high-elevation communities, such as Flagstaff and Show Low. The risks estimated for the Casa Grande region are probably similar to risks in other relatively small, low-desert communities in the State.

Conclusions

The hazardous air pollution research program represents a significant multi-year effort to substantially increase the understanding of the health risks of hazardous air pollutants to the citizens of Arizona. As a first assessment of this scope for Arizona, it was successful in illuminating the level of risk posed by HAPs and the dominant sources of these HAPs.

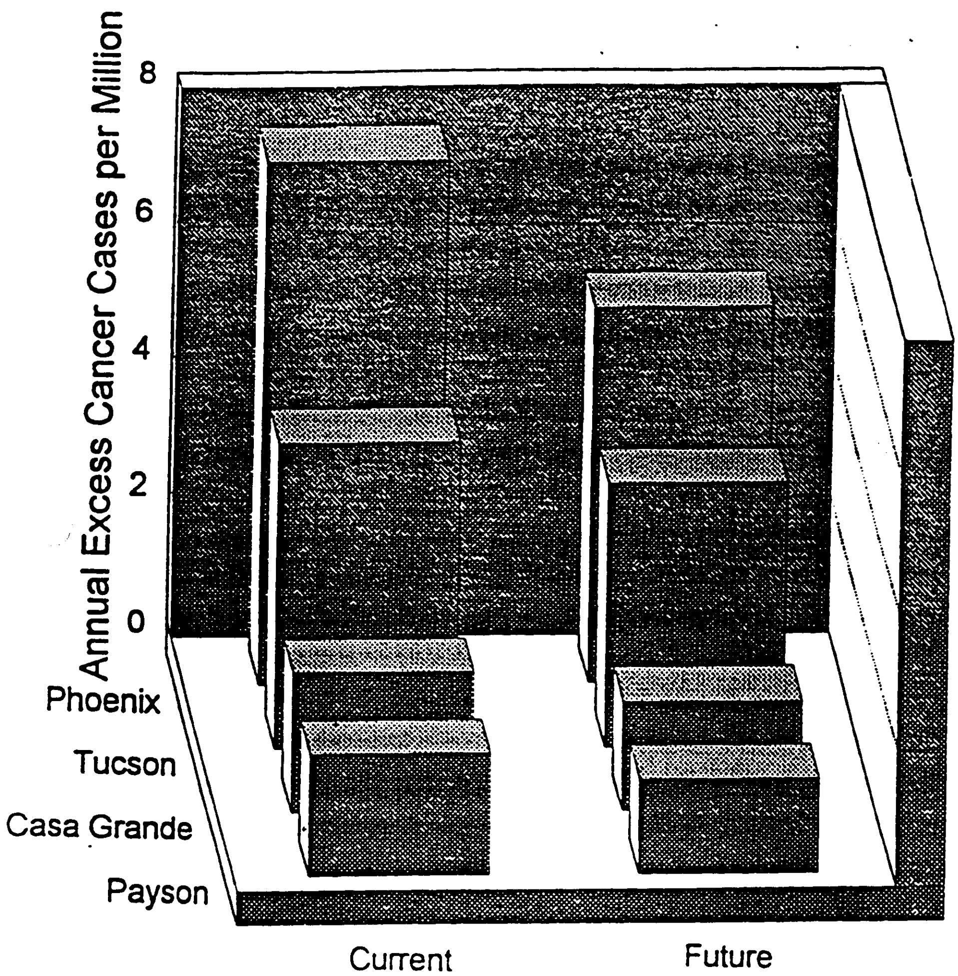

Figure ES-11 Comparison of Current and Future RME Annual Excess Cancer Risks

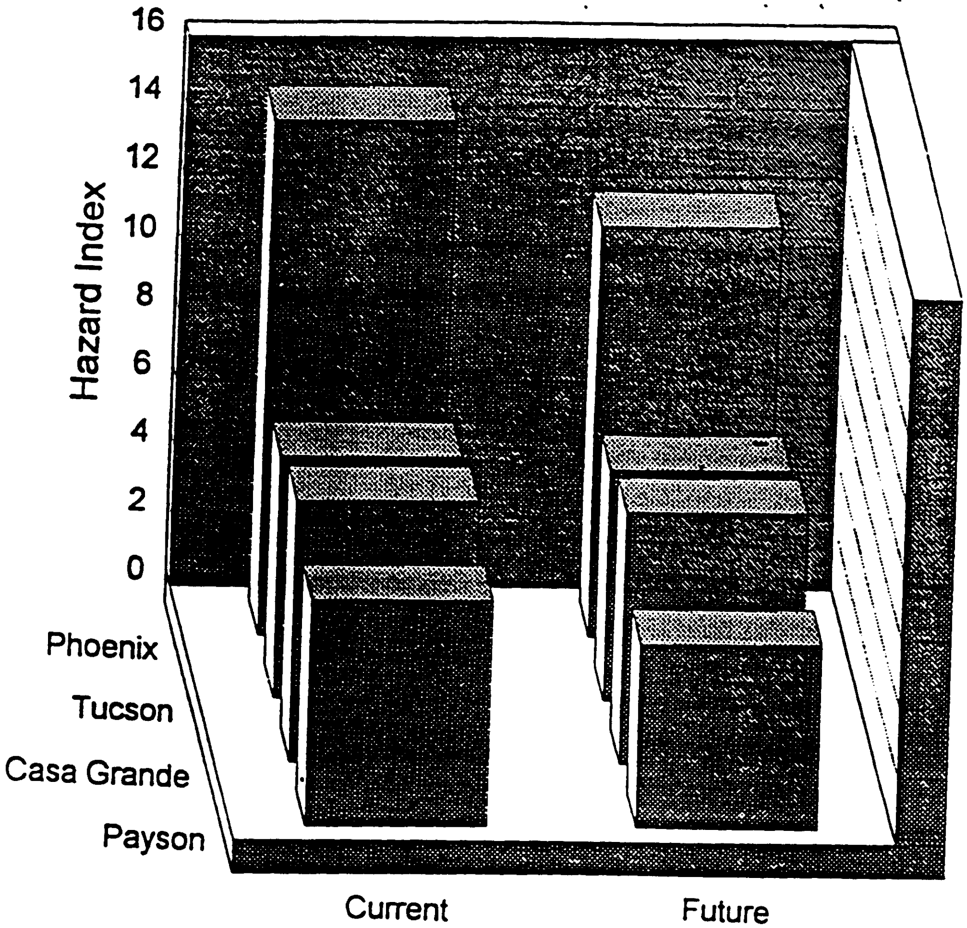

Figure ES-12 Comparison of Current and Future RME Non-Cancer Hazard Indices

Principal findings of the research program included the following:

- The risk to the population from HAPs, based on the concentrations expected to occur in residential neighborhoods, is generally quite small for the typical resident. The results indicate that ~~slightly more than one person per year per million residents is likely to contract cancer due to HAPs exposure in Phoenix~~, and the risk is substantially ~~lower in the other areas studied~~. The ~~highest risk for non-cancer~~ effects is for ~~young children~~, due to their high inhalation rate and lower body weight.

- The residential neighborhood cancer risks were found to be greatest in the most populous areas. For non-cancer risks, the ~~Phoenix area again~~ has the ~~highest risks~~.

- In Phoenix, Tucson and Casa Grande, the ~~overwhelmingly dominant cause~~ of both cancer and non-cancer risks in residential areas was found to be inhalation of organic compounds that result from the ~~operation of motor vehicles~~ and gasoline-powered lawn and garden equipment. In Payson, this combination of sources is the dominant cause of non-cancerous risk, but is exceeded slightly by wood burning as a source of cancer risk.

- Pesticides and other agricultural chemicals were not found to be a significant source of risk in the principal residential areas of Casa Grande, which are removed from the fields where the chemicals are used.

- ~~Inhalation~~ was found to be the ~~only pathway that results in meaningful risk~~ from HAPs. Based on a screening analysis, the risk from HAPs deposited on soil was found to be negligible in comparison.

- Future HAPs emissions are projected to decline significantly and thereby to reduce HAPs risks despite projected large increases in population, vehicle miles traveled, and industrial activity. These reduction are due to cleaner motor vehicle and lawn and garden equipment emissions and actions mandated by the federal Clean Air Act. ~~Continuing population growth after 2005 can be expected to erode these gains~~, however, ~~unless additional measures are taken to continue reducing HAPs emissions~~.

- Because internal combustion engines were found to be the dominant sources of health effects in most areas, the most promising mechanism for further reducing HAPs risks is reduction of emissions from those sources. The most promising next steps are probably the introduction of reformulated gasoline to the urban areas of the state and extension of the current Phoenix inspection/maintenance and Stage 2 gasoline vapor recovery programs to other urban areas.

- Because most of the HAPs risk in the residential neighborhoods of all four regions is attributed to emissions from activities of the populace, a program to educate the public concerning HAPs and the results of this research is desirable.

There are limitations and uncertainties in current understanding that affect the conclusions of the research. While these limitations and uncertainties are unlikely to alter the principal conclusions stated above, they could have an effect on the numerical risk values that have been presented. Some of the principal limitations of this work, that should be recognized when evaluating its conclusions, include the following:

- The results assume that the receptor is exposed to ambient, outdoor air at all times. In reality much time is spent indoors at home, at the workplace, or at school, where the air pollutants and concentrations may differ from those outside.

- The research focused on ~~exposures in typical residential neighborhoods~~. ~~It did not attempt to locate "hot spots"~~. Thus, the risks that are presented represent typical community risks, not risks attributable to living or working in the vicinity of a specific source of HAPs.

- Only those HAPs for which dose-response values are available in the literature and which could be readily measured or for which emissions information was available were evaluated for risks.

The science of assessing risks due to HAPs is a relatively new one, and therefore there are many sources of uncertainty. The principal uncertainties that are likely to be important for this work include the following:

- There are large uncertainties in many dose-response values.

- The emissions inventory that was developed was the first of its kind for Arizona, and is incomplete and has uncertainties. The emissions from mobile sources appear to be best documented, while some point source emissions appear to be in error in both magnitude and location.

- The atmospheric simulation modeling approach that was used did not consider the formation or destruction of HAPs by chemical reactions in the atmosphere, which is likely to have produced errors in the concentration estimates for some reactive chemical species, such as formaldehyde.

- The HAPs measurement data that were used represented only one location in each community and were available for only part of the year in all locations except Phoenix.

Recommendations.

Future research activities that would improve the understanding of HAPs in Arizona and provide for enhanced analyses in the future include the following:

- Complete the ongoing one-year neighborhood sampling programs in Tucson, Casa Grande, and Payson.

- Extend the sampling and risk assessments to other communities, such as Flagstaff and Yuma.

- Complete the planned HAPs evaluation and risk assessment program along the Mexican border, at Nogales and Douglas-Agua Prieta.

- Search out HAPs "hot spots" and determine whether they pose a significantly higher risk than the neighborhood values found during this research program.

- Incorporate the results of the ongoing ADHS epidemiological study in the Gila Basin into the results of this research to reflect health risks from smelter-related emissions.

- Further investigate the health risks of pesticide and other agricultural chemical usage and of dioxins.

- Perform research to reduce the uncertainties in the current results through: (1) additional monitoring; (2) including atmospheric reactions in the atmospheric simulation model; and (3) improving the HAPs emission inventory over time.

- Investigate the potential of using the Research HAPs list and the research program results to improve the foundation for the Air Quality Guidelines of the ADHS.